A Joint HML-KAERI Project: Evaluation of the LLNL and JAERI Torso Phantom using four 50 mm Ge Detectors

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INTRODUCTION

The lung counting system at Korea Atomic Energy Research Institute consists of two ACT II Canberra units. Each unit contains of two germanium detectors cooled by one Dewar. Each detector is 50 mm in diameter and 20 mm thick. The beryllium window is 0.05 mm thick. The ACT II detectors are also fitted with a background reduction device which is a 1.25 cm lead shield that surrounds the two detector unit. The detectors are mounted in a Model 2275 dual purpose lung and whole body counter chamber, also supplied by Canberra. The counting chamber is constructed of 10 cm thick low background steel. The interior is covered with a stainless steel liner. Spectra acquired with the Ge detectors are stored and analysed using Canberra's ABACOS software.

The lung counting system was originally calibrated by Canberra using a third generation LLNL phantom built by Radiology Support Devices. The lung set is sliced and the planar calibration sources manufactured by Canberra. This source is a mixture of $^{241}Am/^{152}Eu$.

This cooperative project, funded by KAERI, was conceived because the LLNL phantom is very much larger than a typical Korean worker, whereas the JAERI phantom (Shirotani 1988) owned by the Human Monitoring Laboratory (HML) is based on Japanese Reference Man (Tanaka et al. 1979) and, therefore, typical of a Korean worker. KAERI wished to implement a new calibration set based on a phantom that was representative of Asian man instead of the LLNL phantom, which is representative of a much larger person.

METHODOLOGY AND RESULTS

The Phantoms: The JAERI phantom was supplied to KAERI with a whole set manufactured for the HML by Pacific Northwest Laboratories which contained $^{241}Am/^{152}Eu$ homogeneously distributed throughout the tissue equivalent material.

The LLNL phantom was measured in the lung counter with and without the B-series overlay plates. These plates simulate 50% adipose and 50% muscle. Unfortunately when they are added to the LLNL phantom's chest plate they change the overall composition as shown in Table 1.

Table 1. AMF values for the HML's LLNL phantom at 20 keV.

Configuration	Top right	Lower right	Top left	Lower left
CPC	0%	0%	0%	0%
CPC + OVP B1	15%	16%	14%	15%
CPC + OVP B2	21%	22%	20%	22%
CPC + OVP B3	26%	27%	25%	26%
CPC + OVP B4	30%	30%	28%	30%

In contrast, the JAERI phantom is either 0% (no overlay), 10% (CZ1xxxx), 20% (CA2xxxx) or 30%(CZ3xxxx) AMF. The two phantoms also differ in their chest wall thicknesses (CWT). Each phantom has slightly different CWT at each of the four detector locations (Kramer and Hauck 1996), but as KAERI analyses summed spectra these have been averaged as shown in Table 2.

Table 2. CWT for the JAERI and LLNL phantom.

LLNL Configuration	CWT (mm)	JAERI configuration	CWT (mm)
CPC	17.8	CPC	19.6
CPC + OVP B1	24.2	CPC + CZ10879	28.1
CPC + OVP B2	30.7	CPC + CZ20853	28.1
CPC + OVP B3	35.5	CPC + CZ30826	27.8
CPC + OVP B4	40.7	CPC + CZ11577	34.9
		CPC + CZ21559	34.7
		CPC + CZ31541	34.7

Counting Protocol: The LLNL phantom was measured with the mixed $^{241}Am/^{152}Eu$ planar sources. The JAERI phantom was counted with the homogeneous $^{241}Am/^{152}Eu$ lung set. Both phantoms were measured with each overlay plate and with no overlay plates. Counting times were long, up to 12 hours (43,200 sec) to obtain good counting statistics at low energies. Shorter counts were also carried out for comparative purposes.

Analysis of Results: Canberra's ABACOS software was used to fit the efficiency data from the mixed sources. The following equation was found to give a good fit to all data sets:

$$Eff = e^{(a + bE + cE^2 + dE^3 + eE^4 + fE^5)}$$

where E = Ln(energy). Energy is in keV
Eff = Efficiency (units)

The parameters 'a' to 'f' are shown in Table 3.

The 17 keV peak from ^{241}Am was analysed separately as plutonium is a concern for KAERI. The data is shown in Table 4. The efficiency labelled as cps/photon was obtained by dividing each ^{241}Am efficiency by the branching ratio. The ICRP value of 30.5 % was used.

Table 3. Efficiency parameters for the LLNL and JAERI phantoms using the LLNL planar sources and the JAERI homogeneous lung set.

Configuration	T (sec)	a	b	c	d	e	f
LLNL	18,000	-474.24	516.67	-227.02	49.678	-5.4017	0.23296
LLNL + B1	18,000	-521.36	566.26	-248.01	54.108	-5.8678	0.25246
LLNL + B2	21,600	-563.05	608.84	-265.39	57.630	-6.2216	0.26659
LLNL + B3	21,600	-585.06	630.77	-274.21	59.400	-6.3986	0.27364
LLNL + B4	28,800	-618.64	665.20	-288.42	62.330	-6.6999	0.28601
JAERI	1,770	-451.45	489.71	-214.79	46.994	-5.1163	0.22116
JAERI + CZ10879	42,597	-558.59	603.43	-263.03	57.175	-6.1843	0.2657
JAERI + CZ10879	1,779	-511.08	548.05	-237.81	51.544	-5.566	0.23893
JAERI + CZ20853	42,548	-541.26	585.05	-254.99	55.38	-5.9814	0.25646
JAERI + CZ20853	1,776	-586.45	636.06	-277.73	60.381	-6.5238	0.27971
JAERI + CZ30826	1,800	-525.93	569.18	-248.44	54.04	-5.8457	0.25102
JAERI + CZ30826	42,597	-542.25	587.36	-256.41	55.756	-6.0276	0.25862
JAERI + CZ30826	1,774	-529.24	570.64	-248.48	53.972	-5.8344	0.25052
JAERI + CZ21559	1,776	-587.03	630.54	-273.38	59.123	-6.3643	0.27219
JAERI + CZ31541	1,779	-635.85	690.06	-301.43	65.561	-7.087	0.30405

DISCUSSION

Efficiency data has been calculated from the information in Table 3 at energies of 17, 60 and 120 keV. The data shows the same general trends so it will be discussed as a whole

The efficiency data all fall on, or very close, to a single curve. However, re-positioning can make a substantial difference in the observed efficiency. A 52% increase in the counting efficiency 1t 17 keV was observed. This underscores what happens when real subjects are monitored. The optimum counting position for these subjects is unknown and the relative position of the intake, if it occurred, is also unknown. Work in the HML suggests that this uncertainty can be as much as a factor of nine (x9) the activity is estimated using a calibration based on activity homogeneously distributed in the lungs.

Table 4. Analysis of 17 keV photopeak from the LLNL planar sources and the JAERI's homogeneous lung set.

Configuration	T (sec)	CWT (mm)	AMF (%)	Counts	cps/kBq	cps/photon
LLNL	18,000	17.8	0	49,361	0.0651	0.21344
LLNL + B1	18,000	24.2	15	23,818	0.0314	0.10295
LLNL + B2	21,600	30.7	21	14,628	0.0161	0.05279
LLNL + B3	21,600	35.5	26	8,887	0.00941	0.03085
LLNL + B4	28,800	40.7	30	6,256	0.00516	0.01691
JAERI + CZ10879	43,200	28.11	10	11,743	0.0151	0.0495
JAERI + CZ20853	42,597	28.10	20	16,837	0.0217	0.0711
JAERI + CZ30826	42,548	27.82	30	20,241	0.0257	0.0843

The other confounding factor, especially at 17 keV, is that the tissue composition of the LLNL phantom with the overlay plates is not the same. This will be discussed in the presentation where it will be seen that the efficiency changes by a factor of almost two at the same CWT. This changes rapidly decreases as the energy increase so that at about 60 keV the tissue composition is not a factor.

Nevertheless, it seems clear from this data that the counting efficiency is independent of phantom type as all the data seems to lie on a smooth curve if one makes allowances for the different tissue compositions.

CONCLUSIONS

This joint study between HML and KAERI has shown that the LLNL and JAERI phantom are equivalent for the purposes of calibrating a lung counting system that consists of two ACT II detectors. Further work will be required with larger area germanium detectors to establish if this equivalence is equipment independent or if larger area germanium detectors or phoswich detectors show the phantoms to be different.

This work has shown that it is unnecessary for KAERI to purchase a JAERI phantom and, therefore, has resulted in a considerable cost saving (approximately $100,000 Cdn) to KAERI.

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